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Abstract

This abstract presents the development of an Atomic Force Microscope (AFM) vertical scanner for surface topography measurements, which is composed of a single axis positioning stage with an integrated metrology system and AFM probe. The scanner is meant to provide the ability to track and measure a maximum topography step of 10 μm with a measurement resolution of less then 0.1 nm and an uncertainty of less than 10 nm (3σ) at a controllable bandwidth of at least 2 kHz.

1 Positioning stage

The design goal of the scanner positioning stage is to provide an accurate movement in one degree of freedom while constraining all other degrees of freedom without introducing errors due to friction and hysteresis. As can be seen in Figure 1, a monolithic flexure stage is chosen, constructed from aluminium and driven by a piezoelectric stacked actuator. Four leaf springs guide the moving element in a single direction (z-axis) with relatively low stiffness (0.5 $N{\cdot}\mu m^{-1}$) while the remaining degrees of freedom are constrained by the relatively high stiffness of the leaf springs. This ensures the stage guiding performance and immunity to straightness errors of the piezoelectric drive. The required stiffness of the piezoelectric actuator is determined by a first resonant frequency greater than 6 kHz to meet the desirable controller bandwidth. This leads to a stiffness of 12 $N{\cdot}m^{-1}$. Using this combination a low actuation force, less than 5 N, is achieved which limits the disturbance force and frame deformation on the structural frame that supports the capacitance gage used for position information and the AFM probe used for force feedback. The movable stage frame possesses circular and triangular cut-outs for mass reduction with moderate loss of stiffness. The presence of the triangular cut-outs yields a non-uniform stiffness distribution across the stage frame elements, which results in a complex, higher order bending shape of the structure when an actuation force is applied. The cut-outs were designed to shape the stage deflection in a way which minimizes its net deformation affecting the displacement and force measurement. In this manner the elastic deformation and the related measurement error was effectively reduced by 60%. The structure is optimized such that the higher resonance modes occur at frequencies greater than 8 kHz which allows for advanced control schemes and higher bandwidths.

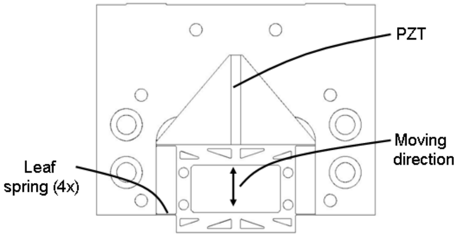

Figure 1: Monolithic flexural stage with the assembled PZT actuator.

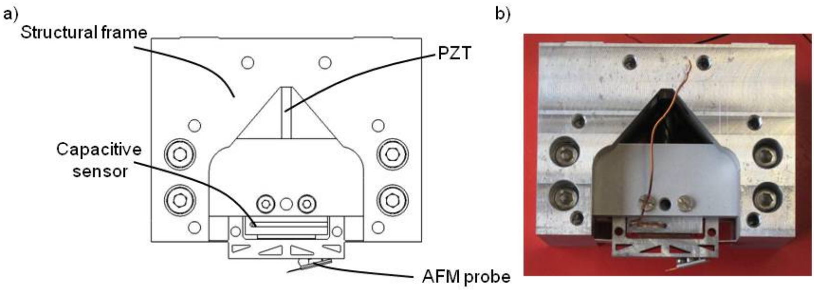

Figure 2: Assembled AFM scanner with cover removed; a) Front view; b) Picture of the AFM scanner with cover removed.

2 Capacitive probe

The capacitive probe was developed together with the structural stage, such that the desired resolution and noise levels are achieved without imposing any constrains on the stage design. The capacitive probe is positioned inside the moving stage to obey the Abbe principle, see Figure 2. The capacitive probe is held by two brackets rigidly connected to the structural stationary frame of the stage, which allows for easy adjustment of the sensing gap between the probe electrode and the target electrode attached to the moving part of the stage. The metrology and force frame are not separated from each other due to the very small actuation forces in the force loop. Additionally, the squeeze film damping occurring between cap gauge probe and target electrodes was kept to a minimum to ensure that there are no appreciable forces acting on the electrodes when positioning at high velocity, preventing deformation of the electrodes and/or the structural frame. The capacitive sensor signal demodulation is performed by an AC demodulation bridge from [1].

3 AFM probe

The AFM probe used is a commercial self-sensing and self-actuating Akiyama probe [2], which does not require an external shaker nor a detection system, thus providing a compact configuration. The probe is mounted to the stage by means of a kinematic mount consisting of 3 spheres, a pre-loading magnet and magnetic steel plate, which yields a good repeatability of the mount when exchanging the probe. Additionally, the probe wiring is soldered to the silver pads painted on a layer of UV glue which covers the pre-loading plate, creating an electrical contact with the probe. The pre-amplification circuit for the Akiyama probe is integrated into the stage assembly in order to keep the probe wiring as short as possible and hence to minimize the parasitic effects. The electronic circuits for Akiyama probe excitation and modulation of its oscillation frequency were realised.

4 Error budget

An error analysis was performed to determine not only the overall error of the system, but also to see which components are the most significant contributors to improve in the future. The error contributors considered during this investigation are: thermal expansion, Abbe and Cosine errors, scanner elastic deformation, static calibration uncertainty of the capacitance gage sensor, capacitance gage measurement uncertainty and elastic deformation of the capacitance gage electrode. The individual error contribution values are listed in Table 1, resulting in an overall error estimation of 5.4 nm (3σ). From Table 1, it can be seen that the largest error contribution is a result from the thermal variations of the temperature controlled environment followed by the scanner elastic deformation. The thermal expansion causes a spurious force feedback due to thermal growth of the scanner and the erroneous position feedback due to the capacitive sensor gap change. The scanner elastic deformation is caused mainly by the stress induced in the stationary structural frame by the frequency dependent piezoelectric actuation forces. In order to limit the related error, the movable mass was reduced to minimize the inertia forces and the stationary structural frame was designed for the high stiffness with additional stiffening obtained from metrology frame brackets.

5 Future work

The future work will be dedicated to the experimental determination of other error sources. This covers the Akiyama probe and the positioning capability of the vertical stage, such as determining the straightness errors, amplifier and the controller.

Table 1: Error sources and their values.

Thermal expansion coefficient	5 nm
Scanner elastic deformation	1.2 nm
Static stage calibration	0.5 nm
Abbe and cosine errors	0.2 nm
Capacitance gage sensor	0.16 nm
Capacitance gauge elastic deformation	0.1 nm

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